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OIL-SHALE RESOURCE INVESTIGATIONS OF THE U.S. GEOLOGICAL SURVEY

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By
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PREFACE

The decade of the 1970's so far has been marked by a sharply increased dependence by the United States on foreign sources of energy. Although this dependence had been growing for the previous 20 years, it was made clearly visible to the American public by the Arab oil embargo of 1973. Since then, energy has remained a topic of public discussion and concern.

The current imbalance between U.S. energy supply and demand and the generally recognized need to increase the domestic production of energy make it appropriate to review our present knowledge of U.S. mineral fuel resources--coal, oil, natural gas, oil shale, and uranium--which in 1975 provided 95 percent of the energy produced in the United States. These conditions also warrant a description of the research that is being done to improve our understanding of these resources, and to determine the effects on the environment of their development.

This is one of four reports on the energy resource investigations being conducted by the U.S. Geological Survey to assess the Nation's coal, oil and gas, oil shale, and uranium and thorium resources. Two other reports provide information about the Geological Survey's programs for assessing the petroleum resources of the U.S. Outer Continental Shelf and for identifying the environmental factors that could affect their development.

The description of the Geological Survey's oil-shale investigations is presented in this report in the context of the underlying socio-economic problem of expanding the domestic production of oil and gas while maintaining acceptable environmental standards. This orientation toward a national mission characterizes each segment of the Geological Survey's energy resources and marine geology programs. Readers who want information about the individual projects that comprise the Oil-Shale Program will find it in the appendices, which also include a bibliography.

It is hoped that this report will give scientists, science administrators, and policy makers, both in government and in the private sector, as well as the general public, a better understanding of the relation of oil shale resources to the Nation's requirements for energy and of the importance of a carefully planned research program of resource assessment and environmental research on this future energy commodity.

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OIL-SHALE RESOURCE INVESTIGATIONS OF THE U.S. GEOLOGICAL SURVEY

by

John R. Donnell

INTRODUCTION AND SUMMARY

National socio-economic problem underlying the Oil-Shale Program

The economy of the United States is a petroleum-based economy. Recent studies of energy-use patterns in the United States have shown that more than 70 percent of the energy consumed in this country is derived from oil and natural gas. The United States consumed an average of about 17 million barrels of oil per day during 1976, derived mostly from domestic production but supplemented in increasing amounts by imported oil. At one point in 1976, imports supplied 50 percent of our petroleum needs, and during the fourth quarter of 1976 imports consistently furnished more than 40 percent of our needs. There is concern about the effect of our growing dependence on foreign sources of oil on our national security, both from a defense posture and economic stability owing to the large balance of payments deficit caused chiefly by oil imports. About 9 million barrels per day of petroleum products and natural gas liquid was consumed by the transportation sector alone in 1975; this exceeds our present domestic production of crude oil by about one million barrels per day. Considerable savings can be made in energy consumption in this as well as in other energy-use sectors through proper conservation measures.

The decline curve for domestic crude oil production that started in 1970, hopefully, may be flattened and possibly temporarily reversed in the near future through additional discoveries and enhanced recovery techniques. At the same time, production of synthetic crude may help relieve the oil shortage. The United States contains, in the thick, rich oil shales of the Green River Formation in Colorado, Utah, and Wyoming, two-thirds of the known oil-shale resources in the world (fig. 1).

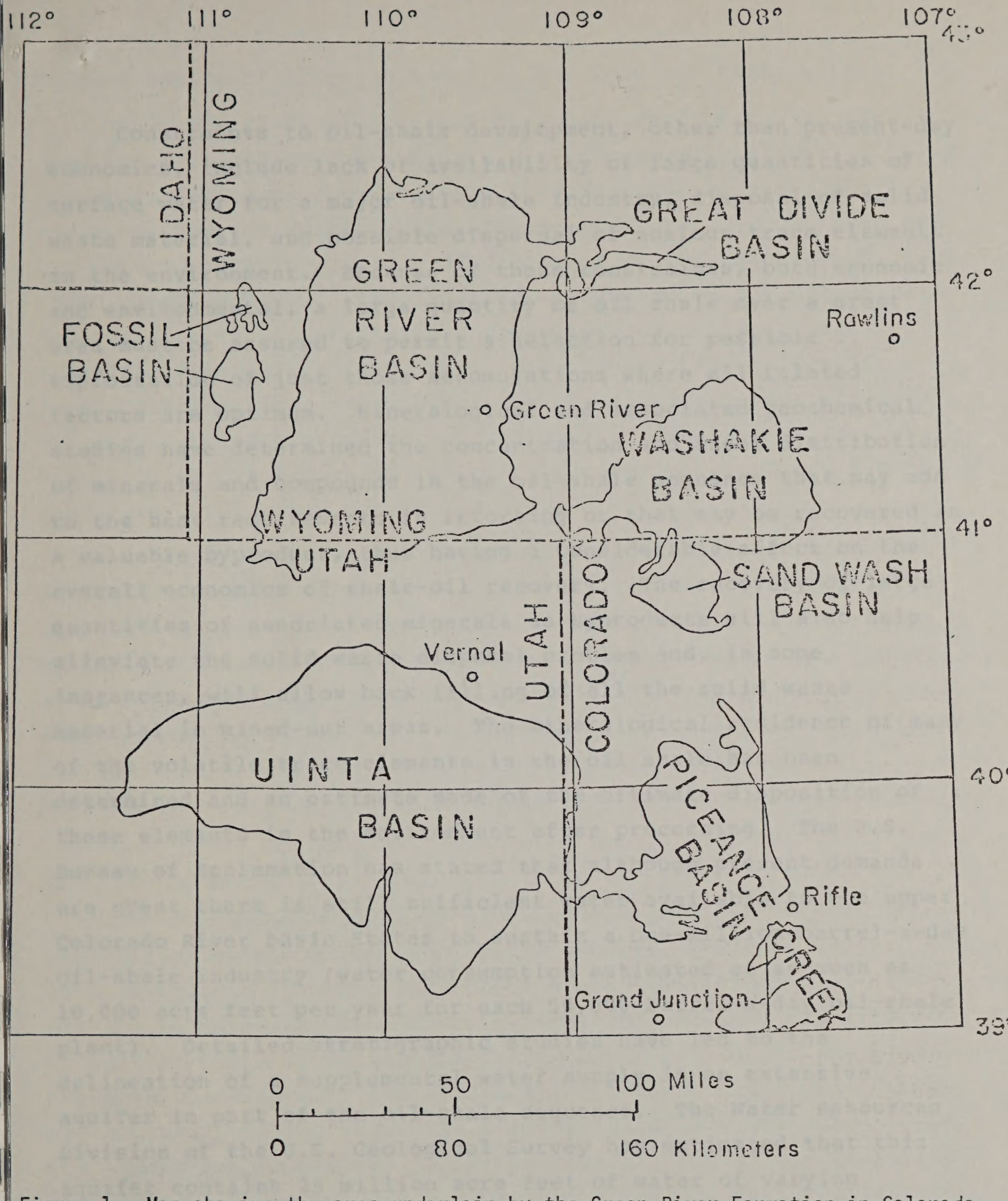

Figure 1. Map showing the area underlain by the Green River Formation in Colorado, Utah, and Wyoming.

Constraints to oil-shale development, other than present-day economics, include lack of availability of large quantities of surface water for a major oil-shale industry, disposal of solid waste material, and possible dispersal of noxious trace elements in the environment. Because of these constraints, both economic and environmental, a large quantity of oil shale over a great area must be assured to permit a selection for possible exploitation of just those accumulations where all related factors are optimum. Mineralogical and associated geochemical studies have determined the concentration and areal distribution of minerals and compounds in the oil-shale sequence that may add to the heat requirements in retorting or that may be recovered as a valuable byproduct, thus having a considerable effect on the overall economics of shale-oil recovery. The recovery of large quantities of associated minerals as byproducts will also help alleviate the solid waste disposal problem and, in some instances, will allow back filling of all the solid waste material in mined-out areas. The mineralogical residence of many of the volatile trace elements in the oil shale has been determined and an estimate made of the ultimate disposition of these elements in the environment after processing. The U.S. Bureau of Reclamation has stated that although present demands are great there is still sufficient water available to the upper Colorado River basin States to sustain a one-million-barrel-a-day oil-shale industry (water consumption estimated at as much as 10,000 acre feet per year for each 50,000 barrel-a-day oil-shale plant). Detailed stratigraphic studies have led to the delineation of a supplemental water supply in an extensive aquifer in part of the oil-shale sequence. The Water Resources Division of the U.S. Geological Survey has estimated that this aquifer contains 25 million acre feet of water of varying quality. The aquifer must be dewatered in areas of mining or *in situ* retorting, and possibly much of the water obtained in dewatering may meet the needs of the oil-shale industry and

relieve the demands on the water of the Colorado River system.

The entire mineral-extractive process depends on the complete delineation and evaluation of the quality of the resource. The siting of a mine and waste disposal area, the mining method and surface retorting method, and the economics of the entire operation are dependent on one or more aspects of resource assessment. Investigations conducted by the Oil-Shale Program furnish the requisite information for optimum site selection for in situ recovery of oil. These site selection parameters include an adequate resource of thick moderately rich oil shale, thick overburden, minimal intraformational water, and knowledge of the concentration and distribution of minerals with endothermic reactions during retorting.

At its optimum level, the Oil-Shale Program would have sufficient funding and staff to provide comprehensive, timely, and unbiased resource assessments for national planning purposes, to delineate resource area boundaries, and to develop new tools and techniques for resource exploration. The oil-shale resources data system, maintained in conjunction with the research program, can serve as a focus for the developing geological and technological understanding of these energy mineral resources.

Commodity program

The Oil-Shale Program involves mainly geologic mapping, stratigraphic studies, mineralogical studies, and computer-related activities. Geologic mapping and stratigraphic studies aid in the determination of the lateral and vertical distribution of the oil-shale deposits, the relationship of the oil shale with overlying, underlying, and laterally equivalent rocks, the dip of the potential mining zone, the composition of the overburden, and the overburden to ore ratio. Mineralogical studies result in the detection of minerals with a byproduct potential for an oil-shale industry, define the mineralogical residence of elements that may have a deleterious effect on the environment, and determine the presence and distribution of minerals that change the thermal

characteristics of oil shale. These factors significantly affect the economics of an oil-shale industry. Computer programs have been developed to utilize information generated by the mapping, stratigraphic, and mineralogical studies in addition to oil-shale assays and chemical analyses. The net result is a series of maps, tables, and graphs depicting the in-place shale and associated mineral resources of the Green River Formation in Colorado, Utah, and Wyoming.

The integrated Oil-Shale Program is also concerned with trying to understand the processes involved in the formation of the oil-shale deposits. The organic fraction of the shale was probably derived mostly from large masses of blue-green algae that flourished in the chemical mix of the lake water. The water composition of the large lakes during their long life span varied from fresh to highly saline. The inorganic fraction of the oil shale, that prior to detailed mineralogical studies was thought to be chiefly detrital in origin, is now believed to have, in great part, precipitated from the highly saline lake waters.

Information derived from the Oil-Shale Program is utilized by the Conservation Division of the U.S. Geological Survey and other agencies of the Department of the Interior in land classification, land exchanges, evaluation of federal prototype oil-shale lease tracts, selection of sites for deep shaft oil-shale mines, and pilot in situ shale-oil recovery projects. Industry has adopted and incorporated in their detailed oil-shale development plans terminology, stratigraphic correlations, oil-shale zonation, and other concepts developed by the Oil-Shale Program. Industry has also extensively utilized computer averaging and histogram plotting programs developed by the U.S. Geological Survey in their oil-shale resource assessments.

Resource estimates of the Green River oil shale in the Piceance Creek basin of Colorado by the U.S. Geological Survey were initiated in 1923 and were based on a few scattered measurements of the outcropping oil shale and shale-oil assays of selected samples from the outcrop. A more recent estimate by the

U.S. Bureau of Mines in 1951 was based on detailed mapping in small areas and shale-oil assays from rotary cuttings of several wells drilled for oil and gas and a few cores drilled to test the oil-shale deposit. Fourteen years later an updated estimate was made by the U.S. Geological Survey, based on much additional geologic mapping and shale-oil assays from numerous oil and gas wells and coreholes. Figure 2 graphically shows the range in estimates of in-place resources from a minimum of 40 billion barrels in 1923 to a maximum of 1.2 trillion barrels in 1964. Basinwide resource estimates have also been calculated for the Uinta Basin in eastern Utah and the Green River Basin in southwestern Wyoming.

The total oil-shale resources of the United States are shown on figure 3. This resource presentation concept was developed by Dr. Vincent McKelvey of the U.S. Geological Survey.[1] Economic feasibility of recovery increases upward on the vertical scale, and the degree of geologic knowledge of the resource increases to the left on the horizontal scale. The upper left quadrant of the diagram encompasses that part of the resource that may now be produced at a profit and is termed reserve. Shale-oil is not now being produced commercially in the United States; therefore, there are no oil-shale reserves.

The potential value of the oil shales in the Green River Formation has been known for many years, and many exploratory coreholes have fairly well delineated the deposit. The 418 billion barrels of measured resources in the paramarginal category is the quantity of 30 gallons of oil per ton of shale in the Green River Formation. This will be of initial interest in an oil-shale industry. The 1,600 billion barrels of measured resources in the submarginal category are in shales of the Green

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[1] U.S. Bureau of Mines and U.S. Geological Survey, 1976, Principles of the mineral resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geol. Survey Bull. 1450-A, 5 p.

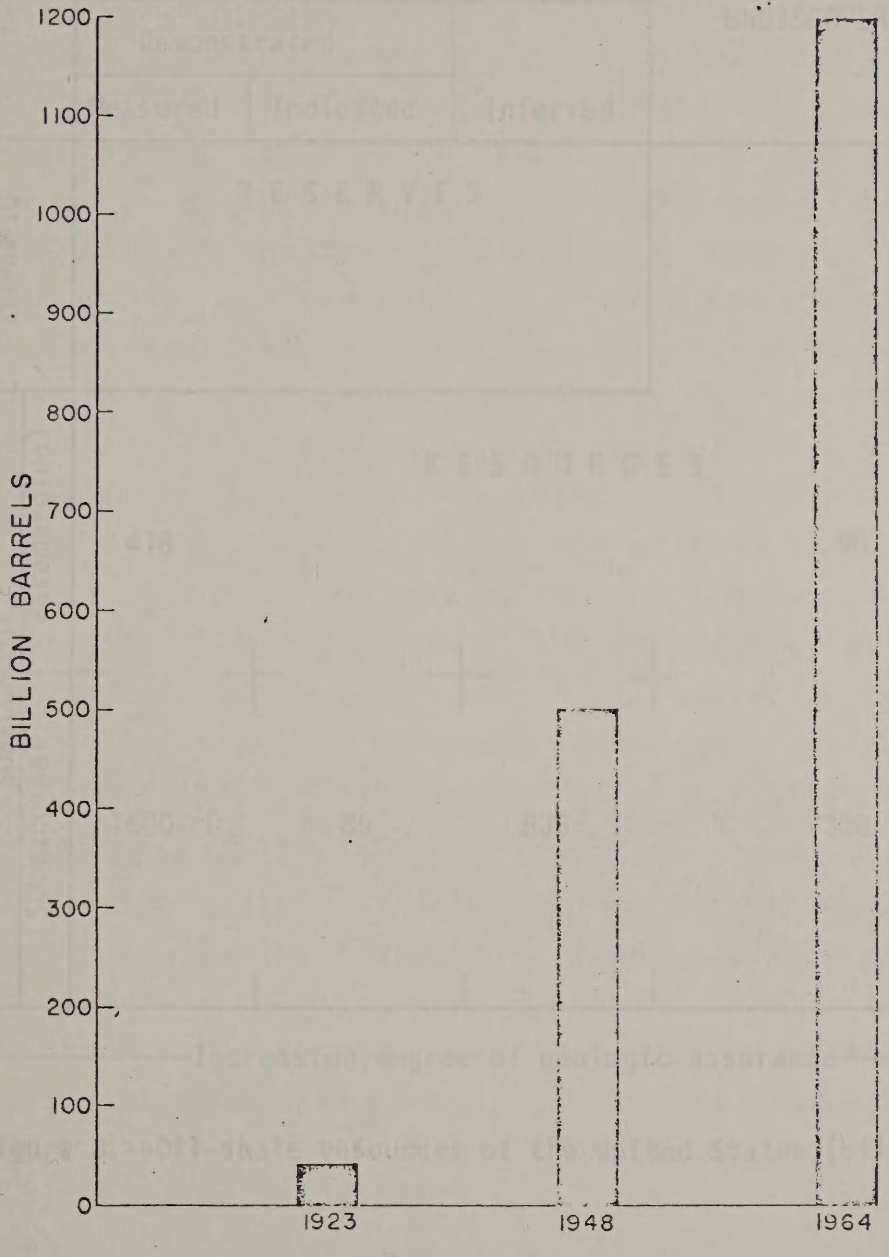

Figure 2.--Graph showing increased knowledge of resource base for oil shale in the Piceance Creek basin, Colorado, as a result of geologic studies.

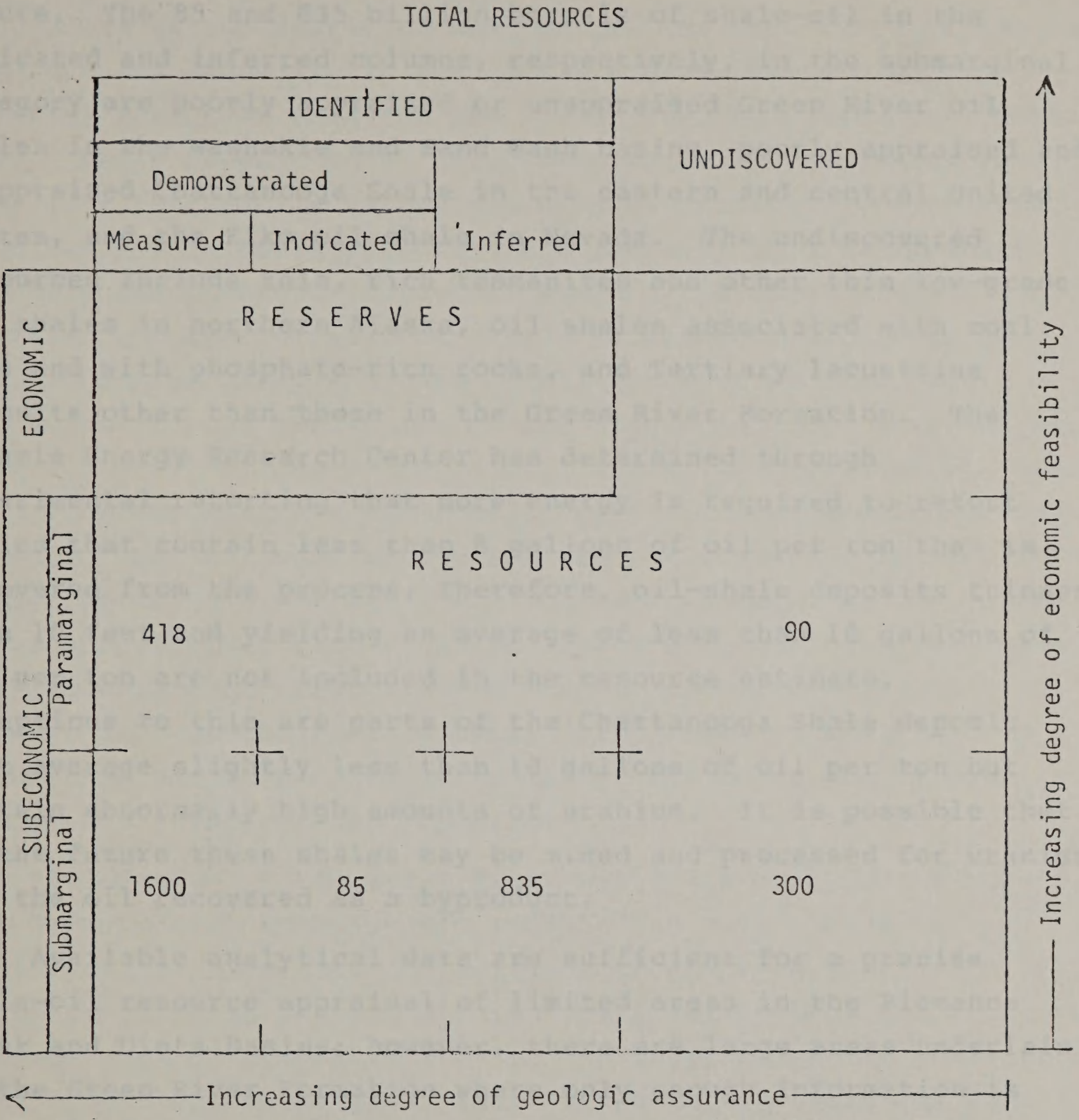

Figure 3.--Oil-shale resources of the United States (billions of barrels).

River Formation that have an average yield of 15 gallons of oil per ton and are presumed to be of economic interest in the future. The 85 and 835 billion barrels of shale-oil in the indicated and inferred columns, respectively, in the submarginal category are poorly appraised or unappraised Green River oil shales in the Washakie and Sand Wash basins, poorly appraised and unappraised Chattanooga Shale in the eastern and central United States, and the Elko oil shale in Nevada. The undiscovered resources include thin, rich tasmanites and other thin low-grade oil shales in northern Alaska, oil shales associated with coal beds and with phosphate-rich rocks, and Tertiary lacustrine deposits other than those in the Green River Formation. The Laramie Energy Research Center has determined through experimental retorting that more energy is required to retort shales that contain less than 8 gallons of oil per ton than is recovered from the process; therefore, oil-shale deposits thinner than 10 feet and yielding an average of less than 10 gallons of oil per ton are not included in the resource estimate. Exceptions to this are parts of the Chattanooga Shale deposit that average slightly less than 10 gallons of oil per ton but contain abnormally high amounts of uranium. It is possible that in the future these shales may be mined and processed for uranium and the oil recovered as a byproduct.

Available analytical data are sufficient for a precise shale-oil resource appraisal of limited areas in the Piceance Creek and Uinta Basins; however, there are large areas underlain by the Green River Formation where only enough information is available for a general appraisal. In the Washakie basin of Wyoming and the Sand Wash basin of Colorado, not enough data are available to make valid estimates; however, limited analytical information combined with geologic mapping indicate that these deposits have less resource potential than the Piceance Creek, Uinta, and Green River Basins. No core-assay information is available near the depositional center of the Green River and Uinta Basins where assays of well cuttings indicate the presence of the thickest and richest oil shales. Basinwide estimates have

also been made of trona in the Green River Basin and of nahcolite and dawsonite in the Piceance Ceek basin. Trona from the Green River Basin is the source of most of the soda ash now utilized in this country; nahcolite in the Piceance Creek basin also is a potential source of soda ash and may be used to clean stack gases in coal-fired power plants; and dawsonite in the Piceance Creek basin is a potentially valuable source of alumina. The trona and nahcolite are interbedded with the oil shale, and the dawsonite is finely disseminated in the oil shale. The Green River Formation contains a resource of 67 billion tons of trona, 32 billion tons of nahcolite, and 19 billion tons of dawsonite. Production of soda ash in the United States has been constant at about 7.5 million tons since 1972. However, the percent of soda ash derived from natural sources, mostly from the Wyoming trona deposits, has increased from 49 percent of the total in 1973 to 70 percent in 1976. Most of the soda ash produced in the United States was consumed domestically. The preliminary figures for 1976 indicate that 6,185 million tons of aluminum were consumed in the United States; and of this, 4,251 million tons were produced in the United States. Most of the raw aluminum ore, bauxite and cryolite, was imported.

Exploration of the Green River oil shale by industry and U.S. Governmental agencies has resulted in more than a half-million shale-oil assays and analyses of sodium minerals. A series of computer storage and retrieval, averaging, and plotting programs were developed to utilize the large amount of analytical data. The computer programs that have been developed may be utilized for resource appraisal of oil-shale deposits with a similar data base from other parts of the United States and other countries of the world.

Federal initiatives

The basic Federal mandate for the oil-shale resource assessment program is the Organic Act that established the Geological Survey in 1879. This Act (43 U.S.C. 31(a)) authorizes the Survey to examine "the geologic structure, mineral resources,

and products of the national domain." More recent authorizations permit the Geological Survey to "conduct geological and geophysical exploration in the Outer Continental Shelf" (43 U.S.C. 1340) and in areas outside the national domain "where determined by the Secretary [of the Interior] to be in the national interest" (43 U.S.C. 31(b)).

Several reports commissioned by the President have given impetus to an expanded national program of energy resource assessment. In December 1973, Dixie Lee Ray, then Chairman of the Atomic Energy Commission, submitted to President Nixon a report entitled "The Nation's energy future." One of the recommendations in this report calls for "enlarging the qualitative and quantitative inventory of domestic resources" as rapidly as possible by improving the "knowledge level of domestic resources and economically available reserves of oil and gas, both onshore and offshore," "the knowledge level of domestic resources . . . of uranium and thorium," the assessment of "the quality, regional distribution, and recoverability of the Nation's coal resources," and the "information base on the distribution and quality of oil shales and tar sands" (p. 98). The Project Independence report of November 1974, also commissioned by President Nixon, does not recommend specific policy actions concerning energy but does note that "all the new oil production is forecast from frontier areas in Alaska, from the Atlantic OCS or from improved tertiary recovery techniques. Each of these requires further exploration or new technology" (p. 42). Elsewhere in the Project Independence report (p. 114), the current levels of uranium resources and uranium exploration are recognized as constraints to the future expansion of nuclear power. Although these reports have not resulted in additional legislative authority for the Geological Survey to conduct energy resource investigations, they have perhaps influenced the Congress to appropriate additional funds for such work under existing statutory authority.

The President's budget, as submitted to Congress each year, recommends an amount of money to be appropriated to support the

Geological Survey's oil-shale resource investigations. A justification that accompanies the budget describes the program, tells how it relates to a national mission or goal, and defines the type and amount of work to be accomplished with the appropriated funds.

As reported in the budget justification for fiscal year 1977, the principal object of the Oil-Shale Program is to assess the oil-shale resources of the United States, with particular emphasis on the oil-shale deposits in the Piceance Creek and Uinta Basins of Colorado, Utah, and Wyoming. Surface mapping and related geological and geophysical investigations provide information about the areal extent of the oil-shale deposits and the nature and thickness of their overburden. Core drilling and the analysis of core samples for oil yield help determine the 3-dimensional distribution of the richest oil-shale beds, as an aid to underground mining or *in situ* retorting. Mineralogical studies indicate the amount and distribution of sodium-aluminum minerals in the oil shale, which may have an economic value. The resource data thus obtained are useful to Federal and State planners and the fledgling oil-shale industry. They also are incorporated in Environmental Impact Statements regarding the potential effects of oil-shale development.

Although the commercial production of oil from the oil-shale resources in the Rocky Mountain area is yet to be attained, the growing body of knowledge about the nature and extent of these resources is a necessary prerequisite to their successful future development.

DESCRIPTION OF THE OIL-SHALE PROGRAM

Scientific and technical problems

Oil-shale investigations are necessary to assess the Nation's resources of oil shale, particularly the rich and extensive deposits in the Piceance Creek basin of Colorado and the Uinta Basin of Utah. Major problems confronting the Oil-

Shale Program are the determination of the areal extent of the oil-shale deposits and the determination of the nature and thickness of their overburden. In addition to the distribution of the oil-shale deposits, an adequate assessment requires knowledge of the quantity and grade of the oil shale as well as knowledge of the distribution and content of their contained trace elements and saline minerals. During the mining and processing of oil shale, escaping trace elements could be deleterious to the environment; and the associated saline minerals, which are potentially valuable byproducts, could be irretrievably lost.

In spite of the vast number of previous studies on the Green River Formation, the origin of the oil-shale deposit and associated saline minerals remains an enigma. Data, collected during the present stratigraphic and mineralogical studies, will contribute to a better understanding of the depositional environment of the oil shale and associated rocks as well as a better understanding of those physical, chemical, and mineralogical changes that occurred after burial of the deposits.

Present state of knowledge.--Geological investigations by the U.S. Geological Survey have shown that oil-shale deposits occur in more than half of the 50 States of the United States. Thin, low-grade deposits of oil shale containing more than average amounts of uranium were deposited in shallow seas that covered large areas of eastern and central United States. Because of the areal extent of the shale, there is a very large in-place resource; but because of the poor grade of the shale, there is presently little economic potential. Inundation by the seas of a sizeable area of California in the vicinity of Santa Barbara and Los Angeles resulted in the deposition of a thick sequence of lean to moderately rich oil shale that contains thin phosphatic zones. These shales are not rich enough over a thick enough interval for oil to be produced commercially. Other phosphate-rich organic shales are in northern Utah, western Wyoming, and southeastern Idaho. These shales are now being mined for phosphate, but no attempt is made to convert the

organic fraction to oil. The richest oil shales in the United States, yielding as much as 160 gallons of oil per ton, occur as small pods in a geologically complex area in northern Alaska. Other thin, lower-grade oil shales that are high in trace metals are also in northern Alaska. These deposits are only of academic interest because of the expense of mining and oil extraction in the geologically complex and remote area. Extensive oil-shale deposits in the United States were formed in lakes that existed in the Rocky Mountain area within the past 50 million years. Many of these deposits, in Nevada and Montana, are small in areal extent or are in areas that are structurally deformed. However, a thick sequence of rich oil shale was formed in sediments of the Green River Formation because of the great lateral extent, ideal climatic conditions, and long duration of lakes in northwestern Colorado, northeastern Utah, and southwestern Wyoming.

Recent efforts under the Oil-Shale Program have concentrated on the Green River Formation of Colorado, Utah, and Wyoming and have produced the following information. The deposit contains 2 trillion barrels of oil and billions of tons of the associated saline minerals, including trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), nahcolite ($NaHCO_3$), and dawsonite ($NaAl(OH)_2CO_3$); these minerals may be used for the manufacture of soda ash, for cleaning noxious gases and particulate matter from stack gases in coal-fired power plants, and in the manufacture of alumina, respectively. There are 25 beds of trona of minable thickness in the Green River Basin of Wyoming that have a total in-place resource of 67 billion tons. Mines in Wyoming are now producing more than a million tons of trona a year. The oil-shale sequence in the center of the Piceance Creek basin is 2,000 feet (610 m) thick, and the lower half of this sequence also contains beds and pods of nahcolite and finely disseminated dawsonite. The in-place resource of nahcolite is estimated to be 32 billion tons, and dawsonite is estimated to be 19 billion tons.

A significant part of the Oil-Shale Program, particularly the segment pertaining to mineralogy and associated geochemical studies, relates directly to environmental considerations and

possible processing problems. The knowledge of the concentration and distribution of the major and minor minerals, compounds, and elements and the determination of the mineralogical residence of some of the most volatile trace elements in both the raw and retorted shales is guiding industry in the selection of extraction processes that are environmentally sound and aiding federal officials in the monitoring of these operations. For example, recent studies show that most of the mercury is commonly in the oil shale in concentrations of less than one part per million. In a retorting operation, the mercury, concentrated mostly in the off gas, could easily be collected from the retort stack. Fluorine in the raw shale may be present in amounts as great as 3,000 ppm and is contained in the minerals fluorite and cryolite and is probably not amenable to being leached from the spent shale. The lateral and vertical distribution of analcime and dawsonite, and the relationship of one with the other have been studied. These minerals have an endothermic reaction and may, if present in sufficient quantities, require an additional 10 percent more energy in retorting than nonanalcimic or nondawsonitic oil shale.

Summary description and current status of program

Geologic mapping.--Geologic mapping graphically depicts the thickness, character, areal distribution, and interrelationship of the various rock types in the geologic sequence. The structure of the rocks, including faulting and direction and amounts of inclination from the horizontal, are portrayed on the maps. The structure contours and topography shown on the maps indicate the overburden above zones of potential economic interest. These maps are a valuable tool for industry and regulatory agencies of the U.S. Government seeking information on the richest and thickest oil shales for purposes of determination of best extraction methods, location of access roads, utility corridors, and plant, reservoir, and waste-disposal sites.

Detailed geologic mapping on topographic base maps at a scale of 1:24,000 (1 inch equals 2,000 feet) has been completed

for two-thirds of the 1,500-square-mile (3,885 km^2) area in the main part of the Piceance Creek basin. This mapping covers the prototype oil-shale lease tracts, the sodium preference right lease tracts, areas nominated for in situ leasing, land exchange, oil-shale patent contests, and the site of the proposed U.S. Bureau of Mines deep shaft mine. A 400-square-mile (1,036 km^2) area in the eastern part of the Uinta Basin has also been mapped at a scale of 1:24,000 (1 inch equals 2,000 feet). This includes the oil-shale prototype lease tracts, one tract nominated for in situ leasing, and a 180-square-mile (466 km^2) area that is amenable to strip mining. A 1,000-square-mile (2,590 km^2) area in the Green River Basin has been mapped at a scale of 1:62,500 (1 inch equals 1 mile). Much of this area is underlain by thick beds of trona. An area of equal size in the Washakie basin has been mapped at a scale of 1:24,000 (1 inch equals 2,000 feet). This area includes the two tracts of land offered for lease in the prototype program.

Three of the active mapping projects in Colorado are in a 500-square-mile (1,295 km^2) area in the southern part of the Piceance Creek basin. This area includes Naval Oil-Shale Reserves 1 and 3, within which is located the ERDA Oil-Shale Mine and Pilot Retorting Facility, and private lands that contain the mines and pilot retorts of Union Oil Co. and Colony Development. A fourth mapping project in Colorado, near the western margin of the Piceance Creek basin, encompasses the area of the federal lease tract C-a. An additional area of 180 square miles (466 km^2) is being mapped in the southern part of the Uinta Basin and is amenable to strip mining. Experiments on oil-shale recovery are proceeding here in a thin, rich oil-shale zone utilizing a horizontal modified in situ concept, similar to that operated by the Germans near Wurtenburg at the end of World War II.

Stratigraphic studies.--A detailed zonation of the oil-shale and saline sequence in the depositional center of the Piceance Creek basin has been established, and the continuity and relationship of these units with lateral non-oil-shale equivalents in the Uinta Basin and marginal areas of the Piceance

Creek basin are being studied.

Individual rich oil-shale beds and altered volcanic ash beds have been recognized, and their remarkable continuity was determined by tracing them along hundreds of miles of outcrop. Reports on the results of stratigraphic studies in the upper part of the Green River Formation have expanded the knowledge of the previously poorly understood complex intertonguing relationship between the lower part of the Uinta Formation and the upper part of the Green River Formation, and has led to the clarification of the stratigraphic nomenclature in the Piceance Creek and Uinta Basins. The characteristics and continuity of potentially economic gas sands in the lower part of the Green River Formation in the Piceance Creek and Uinta Basins are now being studied along with their relationships to their basin-center oil-shale equivalents and their basin-edge equivalents in the upper part of the Wasatch Formation.

Mineralogical studies.--An analysis of the areal distribution and mineralogical residence of major and minor elements has been made for select beds of rich oil shale from cores drilled in the Piceance Creek and Uinta Basins. Four coreholes were drilled under the Oil-Shale Program, two in the eastern part of the Piceance Creek basin and two in the eastern part of the Uinta Basin. Shale-oil assays of the two Colorado cores have been completed by the Laramie Energy Research Center, and X-ray diffraction mineralogy and wet chemical analyses for acid-extractable alumina and water-soluble sodium are being done on splits of the samples prepared for oil assay. Trace element analyses, done under contract for the lessee on one of the lease tracts, are suspect because of possible contamination and are being rerun by the U.S. Geological Survey on thoroughly cleaned core. Splits of these samples are also being analyzed for caustic extractable alumina.

Computer-related activities and resource assessment.--All analyses of shale oil, extractable alumina, and nahcolite from the Green River Formation are being stored on computer discs.

Currently shale-oil assay data from 306 cores in Colorado, 68 cores in Utah, and 52 cores in Wyoming, and analyses of extractable alumina and (or) nahcolite from 52 cores in Colorado have been stored in the computer file. The number of assays and chemical analyses ranges from a few in short cores to as many as 2,000 in extremely long cores, and the total number stored is about 500,000. All shale-oil assays and some of the sodium-mineral analyses have been graphically plotted by the computer at a vertical scale of 1 inch equals 20 feet and a horizontal scale of 1 inch equals 40 gallons of oil per ton. Many of the shale-oil assays have also been plotted at the same horizontal scale but at a vertical scale of 1 inch equals 100 feet. A total of 52 structure, thickness, equal value, and resource maps and accompanying resource tables of the individual rich and lean oil-shale zones in the Piceance Creek basin have been computer calculated and plotted by Petroleum Information, Inc., under contract to the Oil-Shale Program. The same contract provided for the digitizing of nine density and sonic logs from wells drilled for oil and gas in the Uinta Basin and for the conversion of the digitized values to comparable shale-oil values using a formula derived by the Laramie Energy Research Center. These wells were selected from areas where there is little core-assay information, and they help fill in large gaps in the data on shale-oil resources in the Uinta Basin, including a large area in and adjacent to the depositional center of the basin where the oil shales are thickest and richest.

The data and material listed above are being utilized to compile basinwide resource estimates for the whole oil-shale sequence in value categories ranging from 15 to 40 gallons of oil per ton. More detailed estimates are being calculated, in the Piceance Creek basin, for each of seven discrete rich oil-shale zones. All resource estimates for the Piceance Creek basin and the eastern part of the Uinta Basin, where considerable closely spaced information is available, will be compiled on a township-by-township basis; elsewhere, only total basinwide figures will be calculated. The second phase of resource assessment will

involve calculation of resources of nahcolite and dawsonite on a township-by-township basis where sufficient information is available. Additional analytical information on shale-oil, nahcolite, and dawsonite will be added to the data base, and revisions of resource estimates will be made when warranted.

Geophysical support.--An aquifer formed by the leaching of highly soluble sodium minerals in the Green River Formation is estimated to contain as much as 25 million acre feet of water of varying salinity. Due to the origin of this leached zone, the upper and lower contacts are extremely irregular. A precise delineation of the top and bottom of the aquifer will lead to more accurate computer modeling of the ground water systems in the basin. The presence of this aquifer may prove to be either a boon or a serious constraint to oil-shale development in much of the Piceance Creek basin. Any extraction process involving the oil shales underlying the Mahogany zone, whether it be open pit, conventional underground mining, or some type of in situ recovery, will have to contend with the leached zone. This will involve dewatering the zone and either utilizing or disposing of large quantities of moderate to highly saline water.

Studies being conducted for the Oil-Shale Program by the Branch of Petrophysics and Remote Sensing in the Office of Geochemistry and Geophysics involve the possibility of using electrical methods to determine the top and bottom of the leached zone in the Piceance Creek basin. If this program is successful, it will allow potential oil-shale developers to determine the amount of water and the cost of dewatering the section in and adjacent to potential mining zones, and will provide accurate estimates of the volume of ground water that may be available for use in the oil-shale extraction and disposal processes.

Laboratory support.--The laboratory support group, located at the Denver Federal Center, provides support for all projects in the Oil-Shale Program. Services include preparation of thin sections, preparation of rock slabs (polished or stained), mineral separations, specific gravity determinations, grain-size

analyses, X-ray diffraction for mineral identification and abundance, X-ray fluorescence spectromery, atomic absorption spectrophotometry, scanning electron microscopy, and photography of hand specimens or drill core.

Future direction of the program

The part of the oil-shale effort that has been devoted to geologic mapping and thus far concentrated on the area of the thicker and richer oil shale of the Piceance Creek basin will be shifted to the southern part of the Uinta Basin. Here, the Mahogany zone, thin but high in oil potential, is covered by thin overburden and is amenable to recovery through either strip mining or horizontal modified *in situ* recovery. Other detailed mapping projects in the future will be initiated in select areas of the Green River Basin.

Core drilling and analysis of the oil shale for shale oil and associated minerals in areas of sparse information will be continued in each of the States underlain by the Green River Formation. Thus far, three coreholes have been drilled in the Piceance Creek and Uinta Basins. This has been a cooperative effort between the Oil-Shale Program and the Water Resources Division of the U.S. Geological Survey to provide core for analysis and study and to provide additional control points for the hydrologic models of the basins. Detailed shale-oil resource estimates of the eastern Uinta Basin and the Green River Basin and detailed resource estimates of nahcolite and extractable alumina in the Piceance Creek basin will continue to be compiled as an ongoing effort.

Long-range plans involve reconnaissance mapping and resource assessment of other significant deposits of oil shale in the United States and reevaluation of world oil-shale resources.

Relation of program to other groups

Users.--The result of field investigations and field compilations have been used by the Conservation Division of the

U.S. Geological Survey in classifying large tracts of Federal land as oil shale or non-oil shale and in determining the mineral resource comparability of Federal and private lands for the evaluation of proposed land exchanges. Resource assessments of specific areas have been calculated for the Department of the Interior for selection of tracts of land for the Federal prototype oil-shale leasing program and later for insertion in the Environmental Impact Statement for the prototype program. Similar assessments were made for the U.S. Bureau of Mines for the selection of a site for deep-shaft mining in the Piceance Creek basin. The assessments concerned the surface and subsurface geologic conditions and the suitability of the resource, including the thickness and the value of oil shale, nahcolite, and dawsonite. An evaluation was made of resource capability and overall suitability of several sites for the Energy Research and Development Administration's proposed expanded program of research in conventional and modified _in situ_ shale-oil recovery. Naval Oil-Shale Reserves 1 and 3 in Colorado, and Reserve 2 in Utah, were mapped and resources appraised for the United States Navy. Estimates of oil-shale resources available for commercial exploitation and percentage depletion of the resource base under various production scenarios were calculated for the Project Independence Study for the Federal Energy Administration.

All the nonproprietary analytical data in the files of the U.S. Geological Survey, the computer programs developed by the U.S. Geological Survey, and the shale-oil averaging programs developed by the U.S. Geological Survey in cooperation with Exxon Oil Co., have been made available to industry and the general public through publications. The data and the programs have been used by industry to evaluate their private land holdings and by research organizations and universities to generate resource assessments in fulfilling contracts and grants for research studies funded by industry and Federal agencies. As a result of detailed studies under the Oil-Shale Program in the Green River Formation of the Uinta and Piceance Creek Basins, the oil-shale

sequence has now been separated into a series of widespread alternating rich and lean oil-shale zones, individual rich oil-shale beds or groups of beds have been named and correlated regionally, and parts of the upper Green River Formation have been mapped as intertonguing with the laterally equivalent non-oil shale rocks in the lower part of the Uinta Formation in the northern part of the Piceance Creek basin. This zonation along with these correlations and concepts have been accepted and incorporated in the detailed development plans of the lessees of the prototype lease tracts and in reports of private contractors studying the feasibility and economics of various oil-shale extraction methods.

Coordination.--Project descriptions and annual accomplishments of each project are submitted to the Geological Survey of the State where the project is located. The U.S. Geological Survey receives comments from the State Geologist about the original concept of the project and its yearly progress.

Representatives from the U.S. Geological Survey, U.S. Bureau of Mines, U.S. Bureau of Land Management, Laramie Energy Research Center (part of ERDA), and the Rocky Mountain Regional Office of the Secretary of the Interior, form the Oil-Shale Research Information Committee (OSRIC). This committee meets twice yearly to discuss accomplishments of each agency during the past 6 months and plans for the next 6 months and to outline areas of possible interagency cooperation.

Geographic distribution of effort

Post World War II oil-shale activities resulted in reconnaissance mapping of the oil-shale deposits in Colorado, Utah, and Wyoming at scales ranging from 1 inch equals 2 miles to 1 inch equals 4 miles, appraisal of the total shale-oil resources of the three-State area, and an overall estimate of the trona resources in the Green River Basin and of the nahcolite and dawsonite resources in the Piceance Creek basin. Between 1948

and 1973, the Oil-Shale Program has been continuously active in the Piceance Creek basin and intermittently active in the Uinta, Green River, and Washakie Basins. Since 1973, the major effort has been concentrated in the Piceance Creek basin, the area of greatest economic potential. Only minor effort is being expended in the Uinta Basin, and there are no active oil-shale projects in Wyoming at the present time. Figure 4 shows the location of current activities of the Oil-Shale Program in Colorado and Utah.

An exploratory drilling program in both the Pieance Creek and Uinta Basins has been conducted in cooperation with the Water Resources Division of the U.S. Geological Survey. This continuing program has thus far entailed the drilling of more than 5,000 feet (1,524 m) of core from two holes in the Piceance Creek basin and one in the Uinta Basin. The Laramie Energy Research Center laboratories of ERDA have assayed the oil content of the U.S. Geological Survey core samples. The Laramie Energy Research Center also furnished assays and core material for examination and additional analysis from holes they drilled in Colorado.

Summary of program accomplishments in FY 1976 and transition quarter

Accomplishments of the Oil-Shale Program in FY 1976 and the transition quarter are summarized in this section under the following activities: geologic mapping, stratigraphic studies, mineralogical studies, computer-related activities, and coring activities. The location of these activities is shown on figure 4, and the quantity is given in table 1.

Geologic mapping.--Detailed mapping on 7 1/2-minute quadrangle base maps has delineated zones of oil shale, zones of barren rock, areas of unstable ground, and fracture patterns, and has determined the thickness and structure of oil-shale beds and associated rocks (fig. 4(1-7)). Recent mapping shows that organic-poor tongues in the upper part of the Green River Formation, separated by thick nonorganic beds of the Uinta Formation in the northern part of the Piceance Creek basin, merge

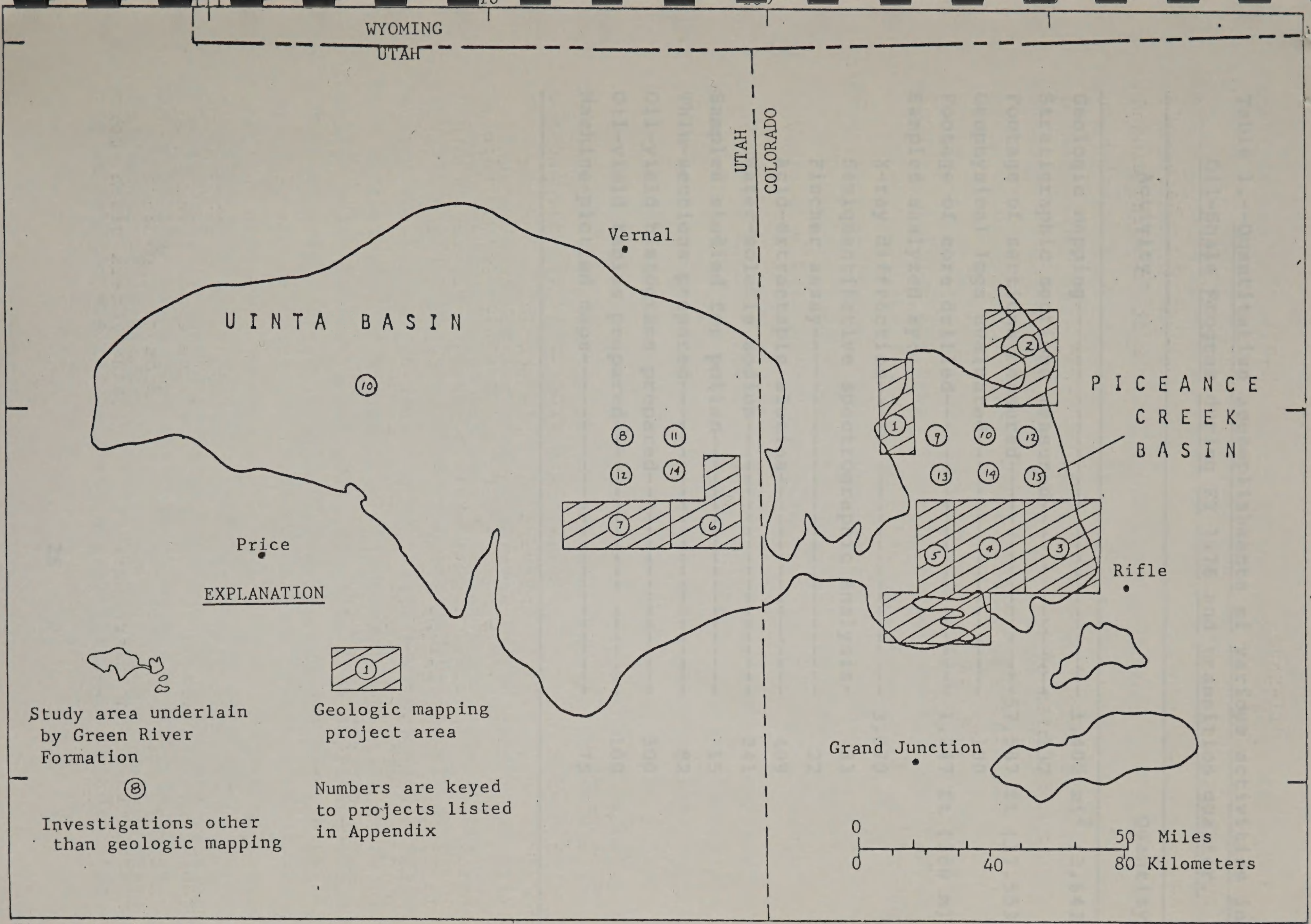
41°
WYOMING
UTAH
UTAH
COLORADO
Vernal
UINTA BASIN
⑩
⑧
⑪
⑫
⑭
⑦
⑥
Price
PICEANCE CREEK BASIN
②
①
⑨
⑩
⑫
⑬
⑭
⑮
⑤
④
③
Rifle
Grand Junction
40°
39°
EXPLANATION
Study area underlain by Green River Formation
Geologic mapping project area
①
⑧
Investigations other than geologic mapping
Numbers are keyed to projects listed in Appendix
0
50 Miles
0
40
80 Kilometers

Figure 4.--Map showing the location of current activities of the Oil-Shale Program in the Piceance Creek basin, Colorado, and the Uinta Basin, Utah.

Table 1.--Quantitative accomplishments of various activities in the Oil-Shale Program during FY 1976 and transition quarter.

Activity	Quantity
Geologic mapping	1,406 mi^2 (3,642 km^2)
Stratigraphic sections measured	137
Footage of sections measured	57,587 ft (17,553 m)
Geophysical logs evaluated	100
Footage of core drilled	1,247 ft (380 m)
Samples analyzed by:	
X-ray diffraction	3,070
Semiquantitative spectrographic analysis	33
Fischer assay	22
Acid-extractable alumina	409
Water-soluble sodium	241
Samples studied for pollen	15
Thin-sections prepared	82
Oil-yield histograms prepared	300
Oil-yield tables prepared	100
Machine-plotted maps	75

and increase in organic content in the southern part of the Piceance Creek basin. The mapping has documented a southward shift of 20 to 25 miles (32 to 40 km) in the center of deposition of Lake Uinta during the later stages of the lake's existence. At or near this center of deposition, 400 to 500 feet (122 to 152 m) of moderately rich oil shale was deposited. Elsewhere in the Piceance Creek basin this sequence of oil shale either was not deposited or was deposited in thin units separated by thick sequences of sediments that lack oil shale (fig. 4(3-5)).

An oil-shale zone, at least 15 feet (4.6 m) thick, is just above the base of the Green River Formation and has been mapped throughout an extensive area in the southwestern part of the Piceance Creek basin. This zone averages more than 15 gallons of oil per ton and will extend the limits of the area to be classified as potentially valuable for oil shale (fig. 4(5)).

Stratigraphic studies.--Gathering and collating surface and subsurface data have led to greater knowledge of the extent and grade of deeply buried oil shales and associated minerals, and to a better interpretation of the events in geologic history that affected the deposition of these potentially valuable minerals. This information has been used in lease-tract selection and experimental mine planning (fig. 4(8-9)).

The location of the area of maximum oil-shale resources in the eastern Uinta Basin has been inferred from correlations of rich oil-shale zones and an isopach map based on sonic and density logs. Now the validity of this inferred location has been strengthened by the results of a computer program which derives estimated shale-oil yield averages from digitized sonic and density logs of exploratory wells drilled for oil and gas (fig. 4(8)).

Mineralogical studies.--Planning for the development of any synthetic fuel resource requires knowledge of those minerals that may be deleterious to the environment or may reduce plant efficiency. Mineralogical studies of the Green River oil shales have determined the presence and quantity of those minerals to

receive special attention during plant operation to prevent damage to the environment or excessive use of energy in converting the organic matter in the oil shale to shale oil (fig. 4(10-11)).

Major and minor minerals were determined for 378 splits from Fischer assayed samples from three drill cores in the eastern Uinta Basin, Utah. The samples are from the zones of highest oil yield at each locality and showed no strong correlation of major minerals with oil yield. These data and other mineralogical studies in the Piceance Creek basin suggest that most of the minerals now present in the Green River oil shales formed after deposition of the enclosing rock (fig. 4(11)).

Studies of the X-ray powder diffraction traces from two U.S. Geological Survey core holes indicate that correlatable mineral zones near the depositional center of the Piceance Creek basin may extend to the eastern part of the basin (fig. 4(10)).

Computer-related activities and resource assessment.--Density and sonic logs from the Uinta Basin, Utah, were digitized and converted to oil yield. The calculated results were plotted at 20 feet and 100 feet per inch on a bargraph, and the data were used to generate average oil yield and thickness values. This information provides control in areas of Utah where previously there was little or no information. These data also support a recently published map that suggests the depositional center of the Uinta Basin containing the thickest and richest sequences of oil shale was farther north than previously thought (see stratigraphic studies).

The oil-shale data analysis program was used to generate information for contouring isovalue (gal/ton), isopach (feet), and isoresource (bbls/acre) maps for 13 stratigraphic oil-shale zones in Colorado. These maps, together with tabulated resources, provide a detailed appraisal of both the distribution of continuous stratigraphic sequences and the oil-yield value of these zones for use in studies of the economics of commercial extraction. This information has been used in land-exchange

comparisons and mining-zone selection (fig. 4(12-14)).

Coring activities.--During 1975-1976, the U.S. Geological Survey drilled three deep core holes to evaluate oil shale in parts of the Piceance Creek and Uinta Basins where reliable data previously had not been collected. Resource estimates for shale oil, nahcolite, and alumina (from dawsonite) based on these new data are greater than earlier estimates. These holes were drilled in cooperation with Water Resources Division of the U.S. Geological Survey and furnished much-needed information on the hydrology of the northeastern part of the Piceance Creek basin and the eastern part of the Uinta Basin.

Program products

The results of research efforts of the Oil-Shale Program have been conveyed to members of the U.S. and State legislative and executive branches of government, industry, and the general public through: (1) Publications in official government journals and outside publications listed in the appendix; (2) talks to professional societies, other Federal agencies, schools, industry and research groups; and (3) field trips and tours through the oil-shale area with members of the petroleum industry, representatives of other Federal agencies, legislative committee personnel, local officials, members of the news media, and citizens affiliated with the environmental movement. In addition, personnel in the Oil-Shale Program have served or are serving on numerous committees sponsored by the National Research Council, Federal government, and professional societies as well as committees jointly sponsored by industry, Federal Government, and State government. These committees have responsibilities in the areas of *in situ* lease site selection, supplemental environmental impact statements, evaluation of accessory elements and alumina in oil shale, program and contract review for oil shale, and alternative energy sources.

OPPORTUNITIES FOR EXTERNAL PARTICIPATION

To help attain the objectives of its various programs, the Geological Survey is authorized by Public Law 85-934 to spend funds through grants for the support of scientific research and for other purposes. Grants may be awarded only to colleges and universities, other non-profit organizations, and State and local governments. They are based on unsolicited research proposals submitted by investigators who believe that they can contribute to an ongoing scientific program conducted by the Geological Survey. Research proposals may be submitted to the Survey at any time, but some programs will consider only those proposals submitted in response to a public announcement of a project to be carried out partly or exclusively through research grants.

Opportunities for grant-supported research projects related to the Oil-Shale Program depend on the nature and scope of the proposed work, its importance to the program, and the availability of funds. Proposals that complement, rather than duplicate or overlap, existing or planned Survey-conducted projects on oil-shale resources have a better chance of receiving support. A prospective grantee may discuss his proposal with appropriate staff members in the Oil-Shale Program before formally submitting it to the Geological Survey.

Detailed information about the procedures for applying for a research grant are contained in a Geological Survey pamphlet entitled "Grants for scientific research." Copies of this publication may be obtained from any Survey office.

The Geological Survey may award a research contract, as opposed to a grant, to any individual or group, including for-profit organizations, that has the capability to deliver the required product, such as a map, a report, rock or mineral samples, analytical data, or a scientific instrument. A contract usually is awarded in response to a Request for Proposals (RFP), which the Geological Survey issues whenever it requires the services of a private organization. The Survey may send copies

of an RFP to known potential contractors, and the RFP also is published in Commerce Business Daily. However, in some circumstances a contract may also be awarded on the basis of unsolicited proposals.

Further information about grants or contracts related to the Oil-Shale Program may be obtained from the Branch of Chemical Resources, U.S. Geological Survey, Box 25046, Federal Center, MS 933, Denver, CO 80225

APPENDIX 1

PROJECTS ACTIVE DURING FY 1976 AND THE TRANSITION QUARTER

Map key (fig.4)	Title and brief description (in parentheses)	Project No.	Project Chief	Address
	GEOLOGIC MAPPING			
1	Geology of oil shales and early Tertiary rocks in the Piceance Creek basin, Colorado. (Detailed geologic mapping and resource assessment of oil shale and associated minerals in the Green River Formation of the Piceance Creek basin. Provides technical expertise for problems concerning development plans, land exchanges, and litigation of oil-shale lands.)	9430-00115	Donnell, J. R.	Denver, Colo.
2	Geology of the Tertiary rocks in the Powell Park area, Colorado. (Geologic mapping and stratigraphic studies in four quadrangles in the northern Piceance Creek basin to determine the areal and vertical distribution of oil shale and associated facies.)	9430-00109	Pipiringos, G. N.	Denver, Colo.
3	Eastern Roan Plateau, Colorado. (Geologic mapping and stratigraphic studies in four quadrangles in the southeastern Piceance Creek basin with special emphasis on the lateral and vertical variations of the Tertiary rocks. Prepare resource assessment of the oil shale and saline minerals and the potential for coal, oil, and gas.)	9430-01370	O'Sullivan, R. B.	Denver, Colo.
4	Central Roan Plateau, Colorado. (Geologic mapping and stratigraphic studies in four quadrangles in the southern Piceance Creek basin with special emphasis on the depositional history of the Uinta and Green River Formations. Prepare resource assessment of the oil shale, saline minerals, and oil and gas potential.)	9430-01345	Hail, W. J.	Denver, Colo.

	Western [illegible] Plateau, Colorado. (Geologic mapping and stratigraphic studies in five quadrangles in the southwestern Piceance Creek basin with special emphasis on the depositional history of the Tertiary rocks. Prepare resource assessment of the oil shale, saline minerals, and potential for oil and gas.)	[illegible]430-[illegible]579	Jo[illegible]on, [illegible] C[illegible]	[illegible]nver, Col[illegible]
6	East-central Uinta Basin, Utah. (Geologic mapping and stratigraphic studies in three quadrangles in the east-central part of the Uinta Basin with special emphasis on an interpretation of the geologic history and evaluation of oil-shale resources.)	9430-01605	Keighin, C. W.	Denver, Colo.
7	Geology of Tertiary rocks in the Agency Draw area, southeastern Uinta Basin, Utah. (Geologic mapping and stratigraphic studies in three quadrangles in the southeastern part of the Uinta Basin with special emphasis on an evaluation of the oil-shale resources.)	9430-01843	Pipiringos, G.N.[1]	Denver, Colo.

STRATIGRAPHIC STUDIES

8	Stratigraphy of the Green River Formation, eastern Uinta Basin. (Establish a detailed stratigraphic framework for the Green River Formation in the Uinta Basin and determine the distribution and interrelations of the various facies with special emphasis on the rich oil-shale zones.)	9430-01409	Cashion, W. B.	Denver, Colo.
9	Stratigraphy of the Green River Formation, Piceance Creek basin, Colorado. (Detailed stratigraphic studies to correlate key horizons and sequences throughout the Green River Formation and to determine the dimensions and lithologies of the lacustrine and fluviatile facies.)	9430-01842	Johnson, R. C.[1]	Denver, Colo.

MINERALOGICAL STUDIES

10	Petrology of the Green River Formation and associated rocks in Colorado, Wyoming, and Utah. (Chiefly subsurface studies of the stratigraphy, mineralogy, and origin of the saline facies and enclosing oil shales of the Green River Formation in the northern part of the Piceance Creek basin.)	9430-00122	Dyni, J. R.	Denver, Colo.
11	Mineralogy of organic-rich Cretaceous and Tertiary rocks, Uinta Basin, Utah. (Determine the mineralogical composition and distribution of the inorganic constituents in oil shale and other organic-rich rocks of Cretaceous and Tertiary age that have economic potential or that will influence the utilization of potential resources.)	9430-01389	Desborough, G. A.[2]	Denver, Colo.

COMPUTER-RELATED ACTIVITIES AND RESOURCE ASSESSMENT

12	Computer applications to resource assessment and mineralogy of oil shale and other organic-rich sediments, Western United States. (Provide Fischer assay and saline mineral data base for oil-shale deposits in Colorado, Utah, and Wyoming, to be used for evaluation of potential lease tracts, land exchanges, and waste disposal areas and for the determination of mineralogical and statistical trends in the oil shale.)	9430-01410	Pitman, J. K.	Denver, Colo.
13	Shale-oil and saline-mineral resource evaluation. (Evaluation of the shale-oil content in the upper part of the Green River Formation in the Piceance Creek basin. Preparation of maps showing the thickness, oil yield, and structure of selected rich oil-shale zones.)	9430-01411	Keighin, C. W.	Denver, Colo.

14	Energy resource data system--Chemical Resources Branch. (Analysis of oil-shale data accomplished chiefly through a contract with Petroleum Information, Inc.)	9480-51515	Sheppard, R. A.	Denver, Colo.
	GEOPHYSICAL SUPPORT			
15	Geophysical research in oil shale. (Using electrical methods, determine the top and bottom of the leached zone in the subsurface of the Piceance Creek basin. A thick, persistent, rich oil-shale zone occurs above the leached zone, and nahcolite and dawsonite of potential economic value occur beneath the leached zone.)	9790-01521	Campbell, D. L.	Denver, Colo.
	LABORATORY SUPPORT			
--	Chemical resources and oil-shale X-ray laboratory. (Provides equipment, personnel, and space for a variety of mineralized, geochemical, and physical property analyses.)	9430-00842	Raup, O. B.	Denver, Colo.

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[1] Funded in FY 1977.

[2] C. W. Keighin became Project Chief in FY 1977.

APPENDIX 2

PUBLICATIONS BY MEMBERS OF THE OIL-SHALE PROGRAM FOR 1975 and 1976 [Symbols in parentheses following the bibliographic listings refer to subprogram elements as follows: C, computer-related activities; GM, geologic mapping; GP, geophysical support; M, mineralogical studies; S, stratigraphic studies]

Campbell, D. L., 1975, Schlumberger electric soundings near Yellow Creek, Piceance Creek basin, Colorado: U.S. Geol. Survey Open-File Rept. 75-354, 28 p. (GP)

Cashion, W. B., and Dixon, G. H., 1976, Isopach map and cross section of the Mahogany zone, eastern Uinta Basin, Utah and Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-797. (GM) (S)

Cashion, W. B., and Roehler, H. W., 1975, Stratigraphic section of part of the Green River Formation and underlying units exposed in Tommy's Draw, western Piceance Creek basin, Colorado: U.S. Geol. Survey Open-File Rept. 75-422, 16 p. (S)

Desborough, G. A., 1975, Authigenic albite and potassium feldspar in the Green River Formation, Colorado and Wyoming: Am. Mineralogist, v. 60, nos. 3-4, p. 235-239. (M)

_______1976, Mineralogy of oil shale in the upper part of the Parachute Creek Member of the Green River Formation in the eastern Uinta Basin, Utah: U.S. Geol. Survey Open-File rept. 76-381, 27 p. (M)

Desborough, G. A., Mountjoy, Wayne, and Frost, I. C., 1975, Influence of caustic and water leaching on analcime-bearing and analcime-free pyrolyzed oil shale from the Green River Formation, Piceance Creek basin, Colorado: U.S. Geol. Survey Open-File Rept. 75-156, 28 p. (M)

Desborough, G. A., and Pitman, J. K., 1975, Interpretation of Fischer assay data for the evaluation of analcime-bearing oil shale in

the Green River Formation, Colorado and Utah: U.S. Geol. Survey Open-File Rept. 75-219, 30 p. (M)

Desborough, G. A., Pitman, J. K., and Huffman, Claude, Jr., 1976, Concentration and mineralogical residence of elements in rich oil shales of the Green River Formation, Piceance Creek basin, Colorado, and Uinta Basin, Utah--A preliminary report: Chem. Geology, v. 17, p. 13-26. (M)

Donnell, J. R., 1976, Global oil-shale resources and costs: Presentation at the UNITAR-IASA Conference on Future Supply of Petroleum and Natural Gas, Vienna, Austria, 15 p. (C)

_______1976, Environments of deposition of oil shale (abs.): Am. Assoc. Petroleum Geologists Bull., v. 60, no. 4, p. 666. (S)

Donnell, J. R., and Pitman, J. K., 1976, Oil-shale Fischer assay data, tables of oil yield values and oil yield histograms of U.S. Geological Survey coreholes CR-1 and CR-2, Piceance Creek basin, Colorado: U.S. Geol. Survey Open-File Rept. 75-580, 83 p. (C)

Duncan, D. C., 1976, Preliminary geologic map of Wolf Ridge quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-753. (GM)

_______1976, Preliminary geologic map of Square S Ranch quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-754. (GM)

_______1976, Preliminary geologic map of Greasewood Gulch quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-755. (GM)

_______1976, Preliminary geologic map of Jessup Gulch quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-756. (GM)

_______1976, Preliminary geologic map of Rock School quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-757. (GM)

_______1976, Preliminary geologic map of Yankee Gulch quadrangle, Rio Blanco County, Colorado: U.S. Geol. Survey Misc. Field Studies

Map MF-758. (GM)

Dyni, J. R., 1976, Trioctahedral smectite in the Green River Formation, Duchesne County, Utah: U.S. Geol. Survey Prof. Paper 967, 14 p. (M)

Fouch, T. D., Cashion, W. B., Ryder, R. T., and Campbell, J. H., 1976, Field guide to lacustrine and related nonmarine depositional environments in Tertiary rocks, Uinta Basin, Utah, *in* Studies in Colorado field geology, Epis, R. C., and Weimer, R. J., eds.: Colorado School Mines Prof. Contr. no. 8, p. 358-385. (S)

Hail, W. J., Jr., 1975, Preliminary geologic map of the Cutoff Gulch quadrangle, Rio Blanco and Garfield Counties, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-691. (GM)

Johnson, R. C., 1975, Preliminary geologic map, oil shale yield histograms, and stratigraphic sections, Long Point quadrangle, Garfield County, Colorado: U.S. Geol. Survey Misc. Field Studies Map MF-688. (GM)

Keighin, C. W., 1975, Tribal lands resource report, Uinta and Ouray Indian Reservations: U.S. Geol. Survey Admin. Rept., 52 p. (C)

______1975, Resource appraisal of oil shale in the Green River Formation, Piceance Creek basin, Colorado: Colorado School Mines Quart., v. 70, no. 3, p. 57-68. (C)

Milton, C. A., 1976, Mineralogy of the Green River Formation of Colorado, Utah, and Wyoming, U.S.A.: Internat. Geol. Cong., 25th, Sydney, Australia, Abstracts, p. 581-582. (M)

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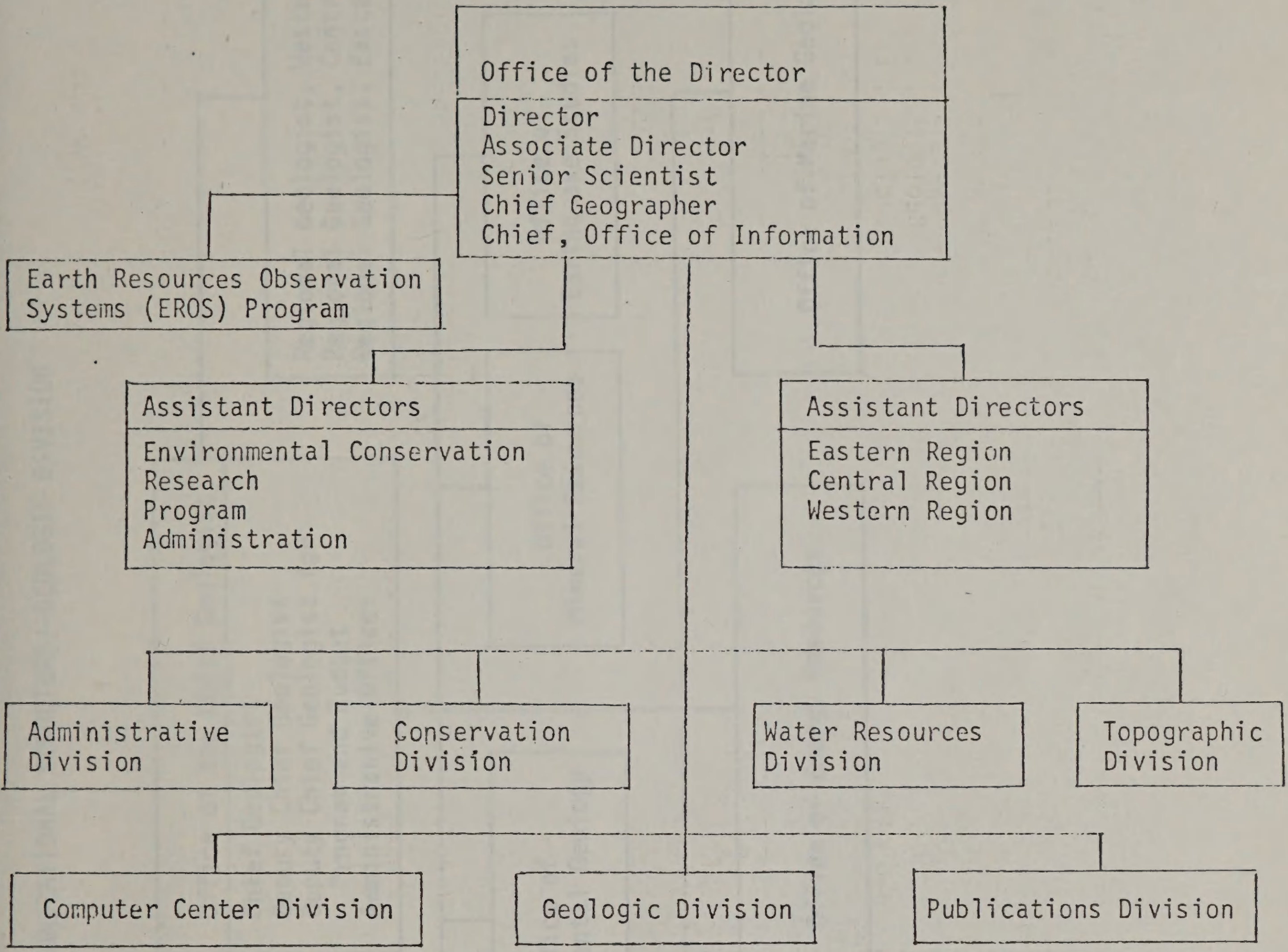
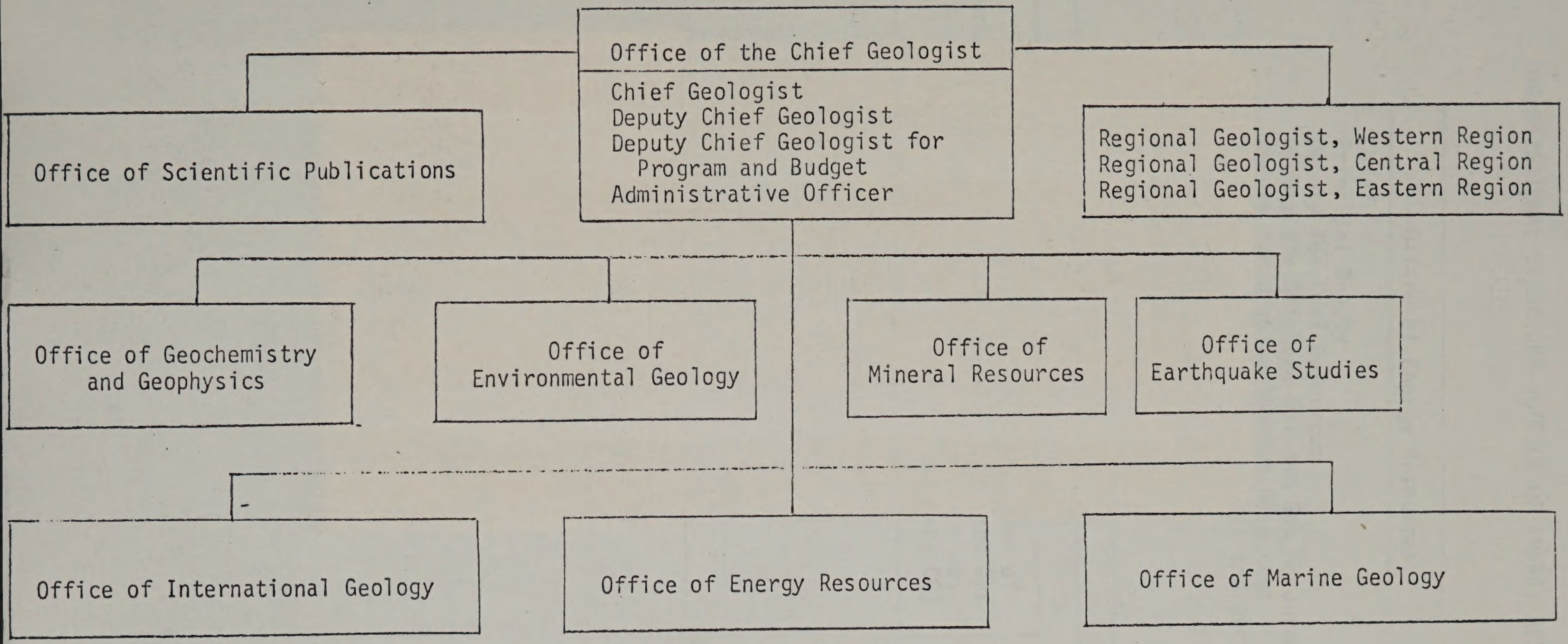
APPENDIX 3

ORGANIZATIONAL STRUCTURE--GEOLOGICAL SURVEY



ORGANIZATIONAL STRUCTURE--GEOLOGIC DIVISION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Chief Geologist
Deputy Chief Geologist
Deputy Chief Geologist for Program and Budget
Administrative Officer
Office of Scientific Publications
Regional Geologist, Western Region
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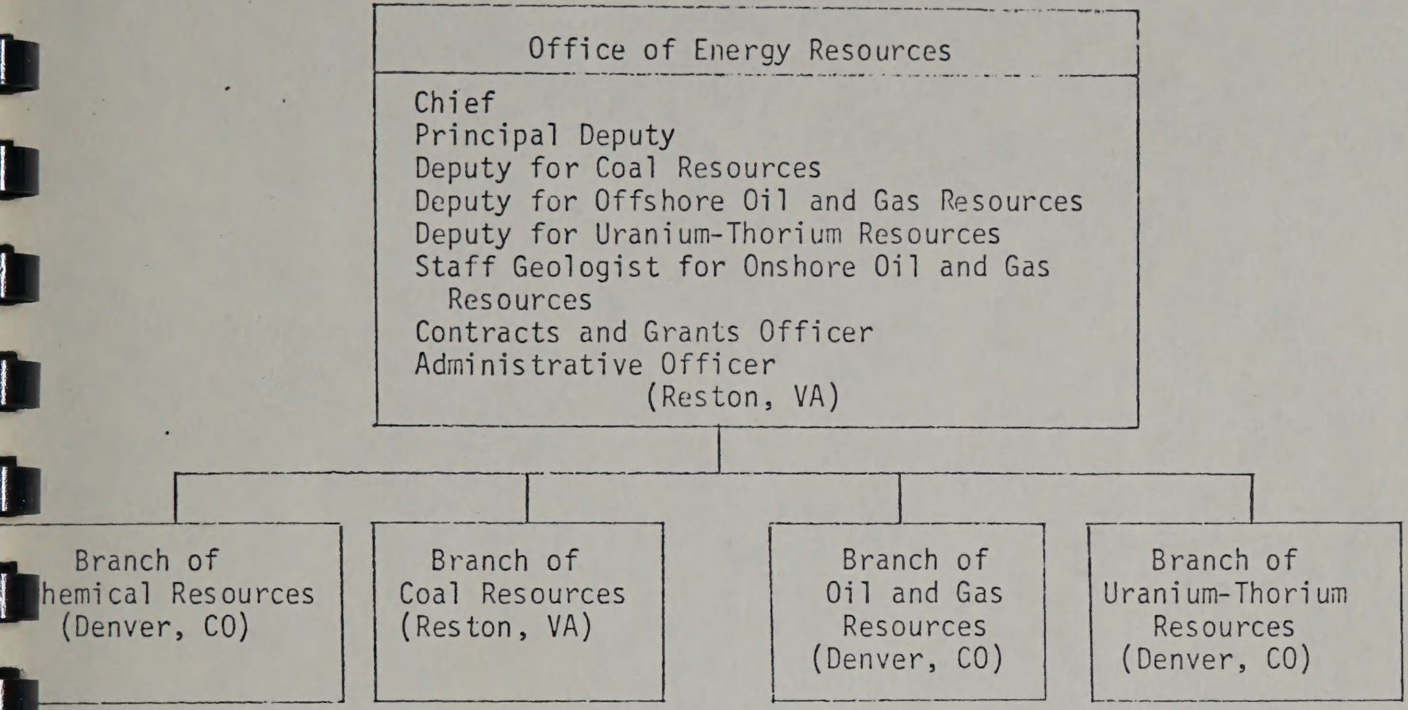
ORGANIZATIONAL STRUCTURE--OFFICE OF ENERGY RESOURCES



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